Experimental analysis of Al2O3/TiO2 nano composite particles in domestic refrigerator

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In this research, an experimental study of a home refrigerator employing R134a as its working fluid and various concentrations of TiO2, Al2O3 and nano composite particles distributed in polyolester (PE) oil lubricant is presented. The PE oil was mixed with all the nanoparticles (NPs) at a volume concentration of 0.1g/L. The experiments are carried out for various compositions, such as R134a with PE oil, R134a with nano lubricant, and R134a with nano composite lubricant. Pressure and temperature measurements from different gauges and sensors that are connected to the system were used as the basis for the analysis. Results indicate that R134a with nano composite lubricant provides the best performance. This combination results in the smallest power consumption of 90.8 W, the maximum actual COP of 2.31, and the smallest compressor work of 61.22 kJ/kg. Therefore, it is advised to use this nano composite fluid mixture as lubricant in household refrigerators.

Keywords: TiO2 nano particle, Al2O3 nano particle, Domestic refrigerator

I. INTRODUCTION

To keep food items fresh, domestic refrigerators are a common fixture in households. The refrigeration system involving vapour compression is the one that is most frequently utilised in household refrigerators. The four main parts of a vapour compression system are an expansion valve, an evaporator, a compressor, and a condenser. The compressor, which is the main power-consuming component of the refrigerator, is powered by an electric motor. Refrigerant R134a serves as the working fluid in household refrigerators. Tetrafluoroethane (CF3CH2F), a member of the HFC family of refrigerants, is also known as R134a and is a common refrigerant found in home refrigerators and air conditioners.

The first study on the interaction of R12 refrigerant with the mineral oil lubricating mixture was conducted by Bambach et al. in 1955. Depending on the Bambach results, Spauschus et al. (1963) examined the performance of oil in vapour compression refrigeration systems with refrigerant. The kind of compressor oil cycling in the system with the refrigerant affects how well a refrigeration system performs, according to the authors. The formulae for entropy, surplus free energy, and mixing heat of the refrigerant oil mixture were developed by the authors. The scientists pointed out that the mole fraction between the molecules of refrigerant and oil plays a major role in the stability of refrigerant oil solutions. According to Choi and Eastman (1995), Das et al.(2006), Wang and Mujumdar (2007) and other researchers, nanoparticles are made of metal (or metal oxide), which speeds up the rate of heat transmission. According to Xuan and Li (2003) nanoparticles have more advanced mechanical, thermodynamic, physical, and chemical characteristics, phenomena, and operations than ordinary materials. According to Kostic (2004), nanoparticles maintain suspended for a lot longer than microparticles do, and they can practically stay poised indefinitely if their concentration is lower than a threshold or they are augmented with surfactants or stabilisers.

According to Nabil et al.,2017, water containing TiO2-SiO2 nano composite particles enhances the fluids' thermal conductivity, making these fluids suitable to be utilized as heat transfer fluids. TiO2-CuO/C nanoparticles were explored experimentally in ethylene glycol by Akilu et al., 2017, who discovered that the fluids' thermal conductivity and viscosity were both increased by nano composite fluids. Wei et a study's, 2017, evaluated the physicochemical characteristics of diathermic oil-based TiO2-SiC nanofluds for heat transfer applications and discovered that nanocomposites with a 0.1% concentration had better thermal conductivity than TiO2 and SiC/oils. By statistically analysing TiO2-CuO in water, Ghadikolaei et al., 2017, discovered that the Nusselt number for nano composite fluids was greater than that of nano fluids as well as base fluids. Al2O3-TiO2 nanocomposites were studied experimentally in water by Charab et al. (2017) who discovered that the fluids' increased thermal conductivity is boosted by the nanocomposites' stability. Monooxide nanoparticles cannot compare to binary oxide nanoparticles in terms of characteristics.

II. EXPERIMENTAL SETUP

A household LG refrigerator with a 175 L capacity serves as the experimental apparatus for this study. The sensors and compound gauges for measuring pressure and temperature are added as further modifications. To identify the pressure locations, pressure gauges with a resolution of 1 kPa are utilised. To measure the temperature at various locations, RTD type PT100 temperature sensors are offered. For measuring the temperature of the freezer, one RTD PT100 washer type temperature sensor is installed within the cabinet. At the base of the freezer, there is a heater whose temperature was managed by a PID controller. The energy delivered to the compressor is measured using a one watt-hour metre. The compressor line and heating lines are each individually linked to a voltmeter as well as an ammeter. Figure 1 displays a schematic illustration of the experimental setup. Tables 1 and 2 provide parameters for refrigerators. The compressor is lubricated with polyolester oil, grade 68 refrigeration oil. The quantities of refrigerant and lubricant added to the refrigerator are tightly regulated throughout the performance test. Each time a test is completed, the lubricant is removed from the compressor and refilled with fresh nanoparticle and nanocomposite particle lubricant combinations. Prior to each test, the refrigerator was completely vacuumed using a vacuum pump to ensure that the system was clean and free of any nanoparticle leftovers. Each test's accurate refrigerant charge is within one gramme.

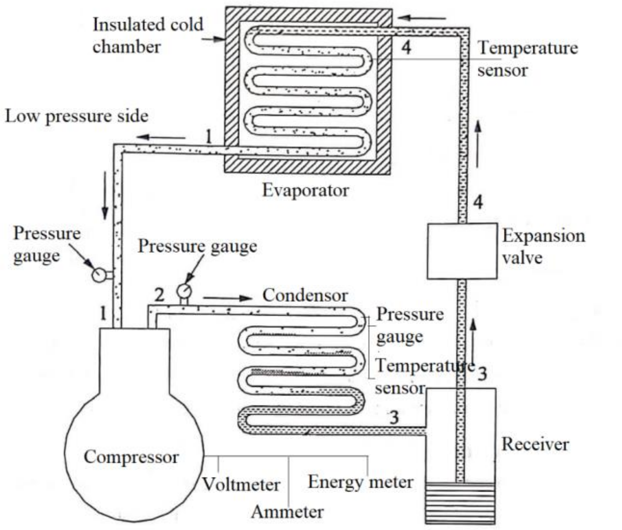

Figure 1. Schematic representation of domestic refrigerator

Table 1 Specification of LG refrigerator

S.No.	Component	Specification
1	Condenser type	Air cooled
2	Compressor type	Reciprocating
3	Refrigerant	R134a
4	Lubricant charge	200 mL
5	Gross capacity	175 L

Table 2 Measuring equipment specifications

Parameters	Instruments	Measuring space	Accuracy
Pressure	Bourdon type gauge	0/35 kgf/cm²	0.1/0.2 kgf/cm²
Current	Digital ammeter	0/6 A	0.1%
Temperature	RTD type PT100	-50 to 150 °C	0.2 °C
Voltage	Digital voltmeter	0/400 V	1%

III. PROCEDURE FOR PRODUCING A MIXTURE OF NANOPARTICLES, NANOCLUSTERS, AND PE OIL

The nano particles are first mixed with the lubricant to create a nano lubricant combination before being put to the refrigeration unit. The mixes are then used as lubrication in the compressor. REinste Nano Ventures Private Limited supplied the TiO2 nanoparticles. Figures 2 and 3 display the TEM picture for TiO2 and the SEM image for Al2O3. Tables

3 and 4 display the physicochemical information for Al2O3 and TiO2, respectively. Because of its superior quality, PE oil (also known as refrigerant oil 68) is frequently used as lubricating oil in refrigeration and air conditioning systems. As indicated in Figure 4, the nanoparticle densities were determined in SHIMADZU AY220 with a 0.1 mg accuracy. 500 mL of PE oil was combined with 500 g each one of TiO2 and Al2O3 nanoparticles in the amounts of 1 and 0.1 g/L, respectively. As illustrated in Figure 4, the combination was then held at room temperature on a magnetic stirrer with a speed range of 1200 rpm to improve the homogeneity of nanoparticle dispersion within the lubricant. In 1 g/L, or 0.5 g/500mL of PE oil, greater TiO2 and Al2O3 nanoparticle settlement has been seen after six months. TiO2 and Al2O3 in the ratio of 0.05 g/500 mL of PE oil, or 0.1 g/L, exhibit clear solubility in the PE oil. As a result, 0.1 g/L of nanoparticles mixed with PE oil have been chosen for the performance test. This 0.1 g/L nano particle concentration in lubricating oil has been employed by numerous researches. Six samples are then created in accordance with the composition stated in Table 5.

Table 3 Physical-chemical information of Al2O3

Properties	**Average value**
Particle size	5-200 nm
Moisture	<1.5
Specific surface area	>10 m^2/g

Table 4 Physical-chemical information of TiO2

Properties	**Average value**
Particle size	5-100 nm
Moisture	<1.5
Specific surface area	50±15 m^2/g

To improve the homogeneity of nano particle dispersion within the lubricant, all samples are held on magnetic stirrers for 48 hours. All samples are held for 6 months to test the dissolution of nanoparticles in lubricant and ensure that they are well dispersed in PE oil. Owing to the nanoparticles' low volume concentrations, neither aggregation nor sedimentation took place, and the nanolubricants remained stable throughout the observations.

Table 5 Nano and nano composite particle composition of samples for POE oil

Sample ID	POE oil (mL)	TiO_2 (%)	TiO_2 (g)	Al_2O_3 (%)	Al_2O_3 (g)	PE/Nano mixing Ratio (g/L)
ID1	200	-	-	-	-	-
ID2	200	-	-	100	0.02	0.1
ID3	200	100	0.02	-	-	0.1
ID4	200	25	0.005	75	0.015	0.1
ID5	200	50	0.01	50	0.01	0.1
ID6	200	75	0.015	25	0.005	0.1

IV. EXPERIMENTAL PROCEDURE

Using a charging connection that was connected to the system, the system was loaded with varying concentrations of PE oil and the refrigerant R134a. The entire system is preserved in an adiabatic chamber with a constant temperature of 27 oC. The experiment was carried out inside a residential refrigerator with the heater running and the temperature within the cabinet held at a constant 25 oC. According to Table 5, the studies for the R134a refrigerant are carried out using six distinct nano and nano composite particle compositions in PE oil as lubricants. The performance of the refrigerator is first evaluated using R134a as a lubricant and PE oil at temperatures of 18°C for the freezer and 27 °C for the ambient air. By monitoring how long the digital energy metre took to blink 10 times, the power consumption rate of the compressor was ascertained. Using the REFPROP 9.0 version, the recorded temperatures and pressures were utilised to calculate the refrigerant's related enthalpy and entropy. Using a vacuum pump that runs for three hours, the system is emptied, and each test sample is charged using a charging mechanism.

V. MATHEMATICAL EXPRESSION

The following paragraphs provide a mathematical structure for performance analysis of various components. The analysis' presumption is that:

The steady state and steady flow conditions.

Losses of potential and kinetic energy are not taken into account

Power consumption

Actual work input to the compressor

$$W_{act} = h_2 - h_1$$

Reversible work

$$W_{rev} = Q_e[\frac{T_0}{T_e} - 1]$$

Refrigeration capacity

$$Q_e = h_1 - h_4$$

$$COP = \frac{Q_e}{W_{act}}$$

Second law efficiency $\eta = \frac{W_{rev}}{W_{act}}$

Total Irreversibility $I_{total} = W_{act} - W_{rev}$

Where h_1= Enthalpy at compressor inlet,

h_2= Enthalpy at compressor outlet,

h_4= Enthalpy at freezer outlet,

T_0= Temperature of surrounding environment, and

T_e= Evaporator temperature

VI. RESULTS AND DISCUSSION

Figure 2 displays the refrigeration system's power usage at an evaporator temperature of 18 oC. In comparison to baseline specimen ID1, the power consumption of test specimens ID2, ID3, ID4, ID5, and ID6 is, respectively, 6.12%, 9.22%, 10.11%, 12.23%, and 10.85% lower. This is accomplished by lowering the pressure ratio in the compressor by adding nano and nano composite particles to PE oil. The compressor effort is reduced due to the decrease in pressure ratio, which lowers the refrigerator's power usage. Sample ID5 uses the least amount of power compared to other samples.

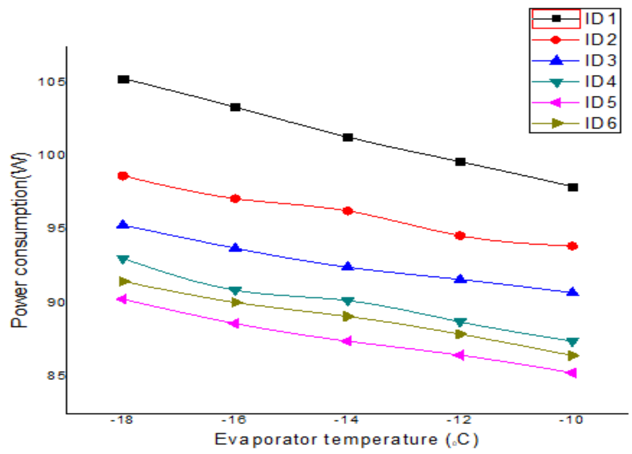

Figure 2. Power Consumption at different evaporator temperature for ID1, ID2, ID3, ID4, ID5 and ID6

Figure 3 displays the actual COP of the refrigeration system at an evaporator temperature of 18 oC. It can be shown that the samples ID2, ID3, ID4, ID5, and ID6 have actual coefficients of performance (COP) that are, respectively, 4.92%, 7.21%, 10.89%, 11.86%, and 10.63% greater than the baseline specimen ID1. This is accomplished by adding nano and nano composite particles, which increases the refrigerant's ability to transmit heat and raises the system's real coefficient of performance. In comparison to other specimens, sample S5 has the highest performance coefficient.

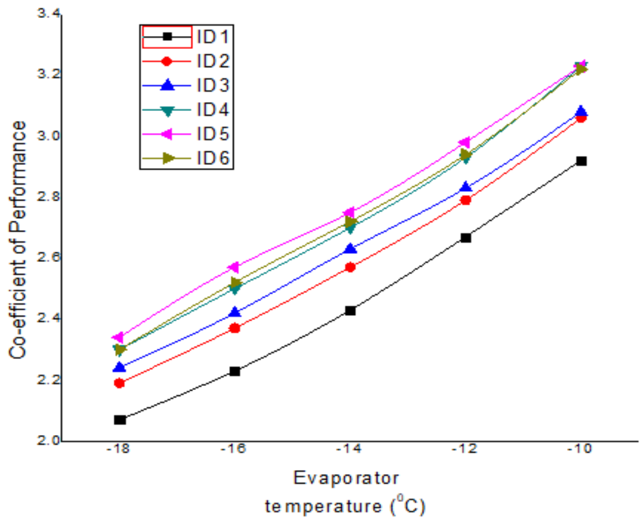

Figure 3. Co-efficient of Performance at different evaporator temperature for ID1, ID2, ID3, ID4, ID5 and ID6

Figure 4 illustrates the refrigeration system's compressor operation at an evaporator temperature of 18 oC. It is evident that the compressor work of examples ID2, ID3, ID4, ID5, and ID6 is, respectively, smaller than that of baseline specimen ID1 by 4.01%, 5.55%, 7.85%, 8.55%, and 7.55%. This is accomplished by adding nano and nano composite particles, which lower the discharge pressure and temperature and hence require less labour from the compressor. The specimen ID5 displays the least amount of compressor work compared to other examples.

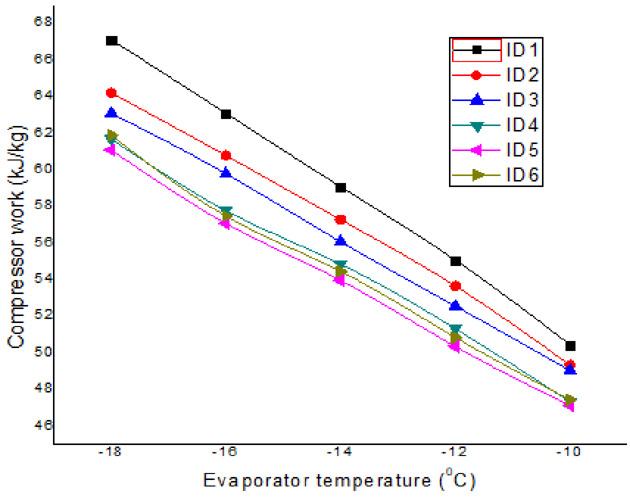

Figure 4. Compressor work at different evaporator temperature for ID1, ID2, ID3, ID4, ID5 and ID6

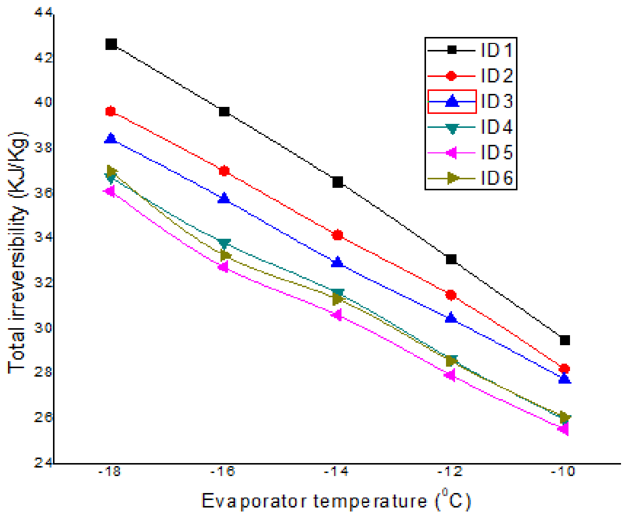

Figure 5. Total irreversibility at different evaporator temperature for ID1, ID2, ID3, ID4, ID5 and ID6

Figure 5 illustrates the refrigeration system's complete irreversibility at evaporator temperature of 18 oC. It is clear that specimens ID2, ID3, ID4, ID5, and ID6 have smaller total irreversibility than baseline specimen ID1, with respective values of 6.72%, 9.52%, 13.58%, 14.91%, and 13.23%. This is accomplished by adding nano and nano composite particles, which increases the reversible interaction between the system and its environment and reduces the system's overall irreversibility. Specimen ID5 displays the system's minimum overall irreversibility compared to other specimens.

VII. CONCLUSION

The conclusions were as follows:

a. In comparison to the baseline sample ID1, sample ID5 displays a minimum power usage that is 12.23% lower. By including nano composite lubricant in the compressor, the pressure ratio is decreased, which lessens the effort required of the compressor and lowers power consumption.

b. The sample ID5, which is 11.86% better than the starting sample ID1, has the greatest performance coefficient. By incorporating nano composite lubricant, the refrigerant's ability to transport heat is improved, raising the system's performance coefficient.

c. The least compressor work is seen in sample ID5, which is 8.55% less than sample ID1 as a baseline. By incorporating nano composite lubrication into the compressor, the release pressure and temperature of the refrigerant are decreased, which lessens the compressor's workload.

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